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Effects of Ag pinning layers on the magnetic properties of Fe/Pt multilayer films

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Tetragonal $L1_0$ ordered Fe/Pt multilayers were prepared by molecular-beam epitaxy on Pt-buffered MgO(001) substrates at 500 °C. An ultrathin Ag (0.5 nm) layer was symmetrically inserted into [Fe/Pt] bilayers with different periods to introduce defects or pinning sites at the interfaces of Ag and Fe/Pt bilayers. The effects of Ag pinning layers in the Fe/Pt multilayers have been studied. The insertion of Ag pinning layers effectively reduced the size of magnetic domains. The distribution of angular dependent coercivity of Fe/Pt multilayers with inserted Ag pinning layers between zero and ten periods, indicates a tendency of the domain-wall motion behavior to be weakened but nucleation mode enhanced. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1855491]

I. INTRODUCTION

$L1_0$ type FePt thin films attract an extensive interest due to the large magnetocrystalline anisotropy constant ($K_u \sim 6.6-10\times10^7$ erg/cm^3) for the application of perpendicular magnetic recording media could achieve up to the terabit recording densities.[1–8] This high K_u value could maintain thermal stability enough for permanent materials to resist thermal fluctuations, and several of the reasons for the great interest are the high coercivity, high energy product, high Curie temperature, and excellent resistance of corrosion in FePt films than that of others. However, to achieve large coercivity and perpendicular anisotropy, a high temperature process is required either during the film growth or postannealing in order to obtain the face-centered-tetragonal (fct) $L1_0$ structure. Moreover, the procedure also causes grain growth and high intergranular interaction between the grains. The defects and impurities in materials have been reported to serve as pinning sites to impede the domain-wall motion or nucleation sites for reversal domains and break the exchange coupling in FePt thin films.[9–11] It has been reported that the grain isolation in FePt films caused by CrMn and Zn top layers.[12] The number and size of the defects may be controlled by varying the thickness of adopting elements to serve as pinning or nucleation sites.[13] It is expected that the defects or pinning sites in Fe/Pt multilayers may be controlled by the periods of Ag inserted layers.

II. EXPERIMENTS AND FILM STRUCTURES

Ten periods (20 nm thick) of [Fe(1 nm)/Pt(1 nm)] multilayers were prepared by an Eiko EL-10A molecular-beam epitaxy deposition system onto MgO(001) substrates with 10 nm thick Pt buffer layer at 500 °C. An ultrathin Ag (0.5 nm) layer was symmetrically inserted into [Fe/Pt] bilayers with two, five, and ten periods by a Knudsen cell. MgO(001) substrates were first cleaned by acetone and alcohol in an ultrasonic bath and then outgassed at 600 °C for 1 h under a vacuum of 5×10^{-9} Torr. The Pt buffer layers were then deposited on the MgO substrates at 600 °C via *e*-beam evaporation at a deposition rate of around 0.05 Å/s. The crystal structure was studied by *in situ* reflection high-energy electron diffraction (RHEED) and *ex situ* x-ray diffraction with Cu K_α radiation. The magnetic properties were measured at room temperature by using a vibrating sample magnetometer with a field up to 1.2 T. The magnetic domain structures of the FePt films were observed under a zero-field state by magnetic force microscopy (MFM).

III. RESULTS AND DISCUSSION

X-ray diffraction patterns for $[\mathrm{Fe(1\ nm)/Pt(1\ nm)}]_{10}$ multilayers without and with two, five, and ten periods Ag pinning layers are shown in Figs. 1(a)–1(d), respectively. In addition to the fundamental (002) peak, (001) and (003) su-

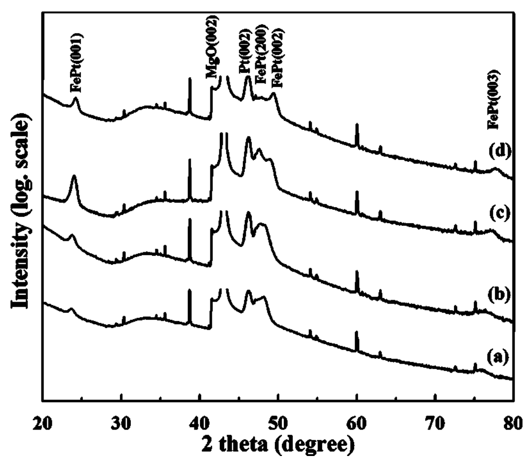

FIG. 1. X-ray diffraction patterns of the Fe/Pt multilayer films with (a) zero, (b) two, (c) five, and (d) ten periods of Ag pinning layers, respectively.

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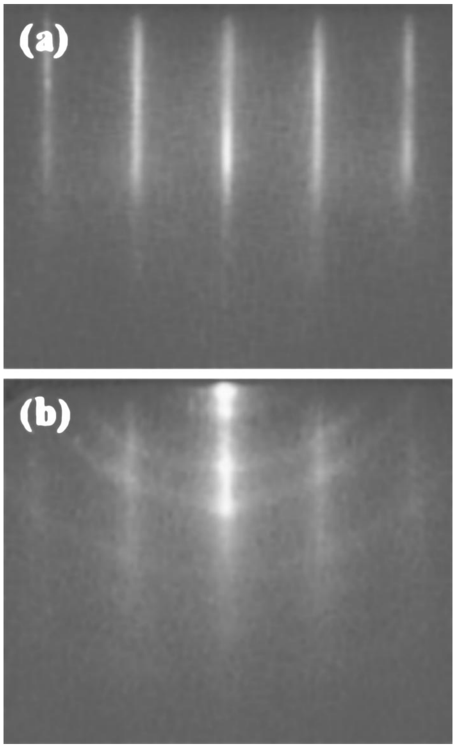

FIG. 2. RHEED patterns of the Fe/Pt films (a) without and (b) with two periods of Ag pinning layers, respectively. The probing *e*-beam is aligned along the MgO[110] in-plane direction.

perlattice peaks of the $L1_0$ ordered FePt phase have been clearly observed for all films. The unlabeled sharp peaks are due to the MgO substrate. In Fig. 1(a), only (00n) diffraction peaks are observed, the Fe/Pt multilayers without Ag pinning layers is strongly textured to the (001) planes which indicated that Fe/Pt multilayers were epitaxially grown on the MgO substrate. The cases of inserted Ag pinning layers system are shown in Figs. 1(b)–1(d), respectively. By inserting Ag layers into Fe/Pt films, the FePt(200) peak is also observed. The result indicates that multi-Ag pinning layers destroy in part the (001) texture of the FePt films, and the RHEED observation also supports the result as shown in Fig. 2(b). But it promotes the ordering degree of $L1_0$ FePt films observed from the FePt(001) diffraction peaks. The Ag layers were also reported in Refs. 14 and 15 to lower ordering temperature. By inserting five periods of Ag layers into Fe/Pt multilayers, FePt(001) peak has the highest intensity, indicating it reaches the highest degree of chemical ordering.

RHEED patterns for the Fe/Pt multilayers without and with two periods of Ag pinning layers are shown in Figs. 2(a) and 2(b), respectively. The probing *e*-beam was aligned along the MgO[110] in-plane direction. The RHEED pattern in Fig. 2(a) is streaky, which also confirms the FePt film without Ag pinning layers is epitaxially grown and relatively flat on the MgO substrates. By inserting two periods of Ag pinning layers into the FePt films, the pattern display getting more spotty and ring diffraction than that without Ag inserted one as shown in Fig. 2(b). This indicates that the film structure of FePt film is getting rougher with other variants while inserting the Ag pinning layers.

Figure 3 shows the out-of-plane hysteresis loops of Fe/Pt multilayers with and without two periods of Ag pinning layers. Perpendicular anisotropy exists for both films. With two periods of Ag pinning layers inserted in Fe/Pt multilayers, the coercivity is 40% larger than that of the films without Ag pinning layers. It is evident that by inserting Ag pinning layers, the saturation magnetization M_s value is decreased with increasing the Ag periods of Fe/Pt multilayers. It can be understood that Ag is a nonmagnetic element and it dilutes the magnetization of FePt films. The coercivity increases with increasing the periods of Ag inserted layers. The highest coercivity was obtained with five periods of Ag pinning layers inserted in the Fe/Pt multilayers. The enhanced coercivity is due to the Ag layer that induces pinning effects at the interfaces between the pinning layer and the Fe/Pt multilayers. With increasing the periods of Ag layer to ten, the coercivity decreases drastically even less than that of the Fe/Pt films without Ag pinning layers. This is because ten

TABLE I. Out-of-plane coercivity ($H_{c\perp}$) and saturation magnetization ($M_{s\perp}$) values as a function of the periods of Ag pinning layers for the Fe/Pt films.

Ag periods	$H_{c\perp}$ (Oe)	$M_{s\perp}$ (emu/cc)
0	4390	560
2	6310	481
5	7732	456
10	3941	412

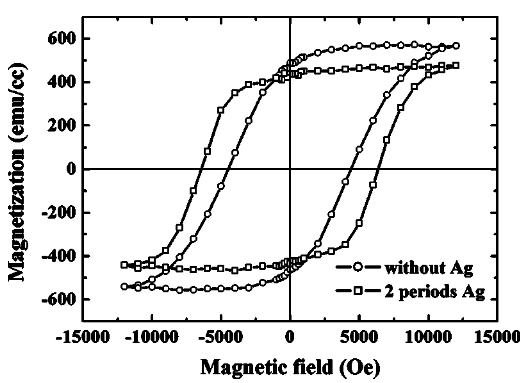

FIG. 3. Out-of-plane hysteresis loops of Fe/Pt multilayers with and without two periods of Ag pinning layers.

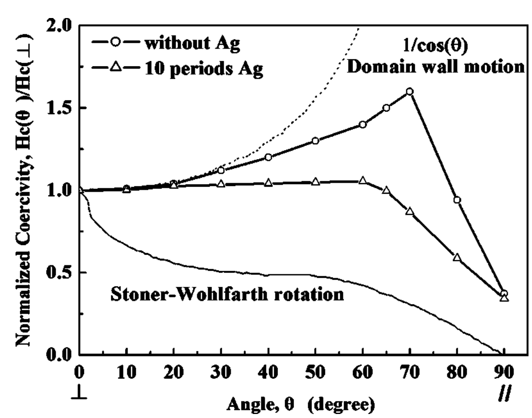

FIG. 4. Angular dependence of coercivity for the Fe/Pt films without and with ten periods of Ag pinning layers. The zero angle refers to the film perpendicular direction.

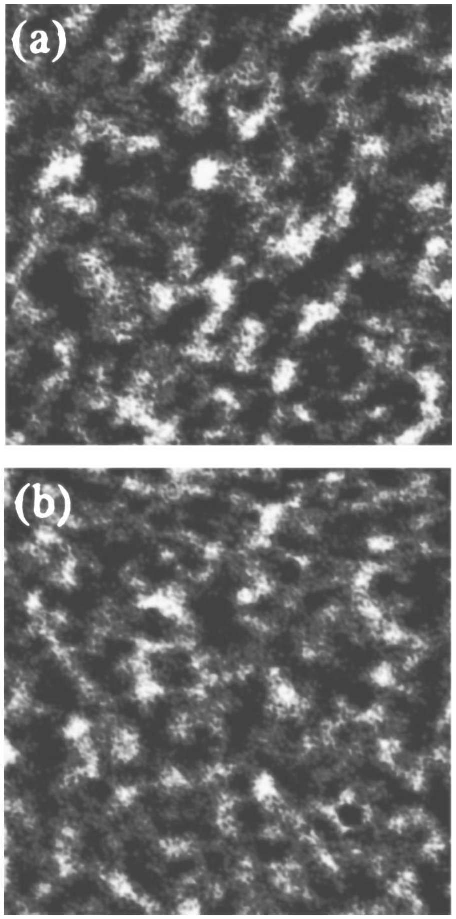

FIG. 5. MFM images of the Fe/Pt multilayers (a) without Ag pinning layer and (b) with two periods Ag pinning layers. The scale is $8 \times 8\ \mu m^2$.

periods of Ag inserted layers would introduce larger inhomogeneities on the interfaces, it may serve as the nucleation sites for the reversal domains that would deteriorate the coercivity of the Fe/Pt films. The perpendicular coercivity $H_{c\perp}$ and saturation magnetization $M_{s\perp}$ values as a function of different periods of Ag pinning layers are shown in Table I.

Figure 4 shows the angular dependence of coercivity for the Fe/Pt multilayer films without and with ten periods of Ag pinning layers. The typical domain motion mechanism and the Stoner–Wohlfarth (SW) model are also shown in Fig. 4. The angular dependence of coercivity profile for the Fe/Pt films without Ag pinning layer shows a typical domain-wall motion behavior. With increasing the periods of Ag pinning layers to ten, the angular dependence of coercivity profile becomes flattened, which is close to the rotation mode dominated in the Fe/Pt multilayers. It indicates a tendency of weakened domain-wall motion behavior but an enhanced nucleation mode mechanism in magnetization reversal process with increasing the periods of Ag pinning layers. Being characteristic of SW rotation mechanism, the domain size would be reduced and the exchange coupling strength decreased in the Fe/Pt films with Ag pinning layers.

Figure 5 shows the MFM images for the Fe/Pt films (a) without and (b) with two periods of Ag pinning layers, respectively. It is evident that the average size of the magnetic domains decreases dramatically by inserting the Ag pinning layers. The separated magnetic domains caused by the Ag pinning layers, which may inhibit the domain-wall extension, thus effectively enhances the coercivity of the Fe/Pt films.

IV. CONCLUSIONS

The effects of Ag pinning layers in the ordered Fe/Pt films have been studied. The coercivity enhancement of the Fe/Pt multilayers is because the Ag pinning layers induced smaller defects that form pinning sites to inhibit domain-wall movement. From the distribution of angular dependent coercivity of Fe/Pt films with inserted Ag pinning layers between zero and ten periods, the mechanism of magnetization reversal was observed with a tendency that the domain-wall motion behavior be weakened but nucleation mode enhanced.

ACKNOWLEDGMENTS

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